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SMOKELESS POWDER

AND

ITS INFLUENCE ON

GUN CONSTRUCTION.

BY

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OF MINING AND MECHANICAL ENGINEERS;
AUTHOR OF 'A TREATISE ON THE APPLICATION OF WIRE TO THE
CONSTRUCTION OF ORDNANCE'; 'INTERNAL BALLISTICS,'
ETC., ETC.

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PREFACE.

In the last chapter of my recent treatise on 'Internal Ballistics' I alluded to the new powders which were then attracting the attention of artillerists.

Referring to their probable nature, I observed that the introduction of any ingredients which would either increase the volume of gas or its temperature, or both together, would not only explain the apparently anomalous action of these new powders, but probably result in the discovery of a still more powerful agent.

Since then this has apparently been accomplished, and the old charcoal powder appears to be doomed to yield to this more powerful rival.

But the adoption of this rival, whose properties are as yet only imperfectly known, is not to be viewed without anxiety. Can it be used with advantage, and above all with safety, in our new type forged steel guns? If not, what changes will its use involve in gun construction? What will be its effect as regards erosion? How will it be affected by storage and change of climate?

These are important questions, to which I do not pretend to give complete answers, but I hope that the following remarks will be of some use in directing attention to the problems upon the solution of which future gun construction and ballistic practice largely depend.

J. A. Longridge.

Greve d'Azette, Jersey.
August 1890.

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SMOKELESS POWDER.

I.

INTRODUCTORY.

1. In few paths of science has the march of progress in the latter part of the nineteenth century been more remarkable than in the development of material for warfare.

2. Less than half a century ago, the heaviest guns in our service were the old 68-pounders, weighing about five tons, and firing, with a charge of 20 lbs. of powder, a spherical 68 lb. projectile to which it gave a velocity of about 1500 feet per second—a ballistic effect equal to an energy of 1060 foot-tons.

3. The heaviest service gun of the present day is the 110-ton gun, firing a projectile of 1800 lbs., with a charge of 850 lbs. of powder, and a velocity of 2100 feet per second, equivalent to an energy of 55,000 foot-tons.

4. In the absence, in this country, of the definite knowledge of the action and properties of powder (acquired through the researches of M. Sarrau, in France), the adaptation of the powder to the gun, and, *vice versâ*, of the gun to the powder, has been a problem, the solution of which, so far as it has been solved, is of an empirical nature, so that the progress made in gun construction and powder manufacture has been of a somewhat erratic description.

5. After the day of pebble powder came that of P_2 or C and C_2, then that of prismatic, succeeded by that of brown cocoa, and finally that of the so-called E.X.E., which

a few months ago was looked upon as the *ne plus ultra* of gunpowder for heavy guns.

6. The line taken by gunmakers has been tolerably consistent throughout. They have aimed at reducing the strength of the powder, keeping down the pressure, and making up for this by increased charges, enlarged powder chambers, and increased length of gun.

Following out this line they have arrived at charges of one-half, or more, of the weight of the projectile, and at guns of 30 to 40 calibres in length, but with a maximum pressure limited to about 17 tons per square inch.

7. In vain the argument has been urged that, by strengthening the guns instead of weakening the powder, the same ballistic results could be obtained with greater convenience and less expense. It has been shown, both theoretically and practically, that wire guns can be made as safe under a pressure of 30 tons as forged steel guns under a pressure of 17 tons; but though a few experiments in this direction have been made at Woolwich, they have been made in a half-hearted way, extending over long intervals of time, during which the construction of the type of forged steel gun has been rapidly proceeded with, and may be said practically to include the whole of our new armament.

8. These latter guns are designed specially for the use of such powders as the brown cocoa and E.X.E., that is to say, powder of which a very large charge is required.

9. Until quite recently our artillerists have been in a happy frame of mind. They had got, or were very rapidly getting a sufficient supply of large guns of what they thought to be the best possible type, and they had the new E.X.E. powder, the best powder in the world. They had but to rest and be thankful.

10. That rest has been of short duration. From Germany and France came rumours of a new powder giving wonderful ballistic results, and at the same time smokeless, or nearly so.

11. Although much secrecy has been maintained with

respect to the nature of the new powders, yet the results have been so far made public, that it is no longer doubtful that they will give ballistic results largely exceeding those obtained from cocoa and E.X.E., with considerably reduced charges and no excessive maximum pressure.

12. This being so, the question arises, how far are our new type guns suited to the new powder, and to what extent shall we require a new armament, in order to reap the full advantage of the new powder? It is proposed to discuss these questions by the light of such knowledge as the author can bring to bear upon the subject.

13. This knowledge is too limited to enable him to produce a "treatise on the use of smokeless powder," but it may perhaps be useful in explaining in some degree the difference of action between the old and new powders, and the approximate results obtained by the use of the latter, both as regards ballistic effect and the development of construction of guns suitable to its use.

14. The subject is divided into the following parts:—

The nature of the new powder and the results of its decomposition as regards the volume of gas produced per unit of weight, the heat evolved, the temperature of combustion and a comparison with pebble powder, as a type of the old powders, the "Potential" and "Force" of the powder.

An examination of the ballistic effects of the new powder in French and German guns.

An inquiry into the pressures in the chase of Canet's 15 cm. Q.F. gun, with B.N. powder, and a comparison with a full charge of pebble powder in the same gun.

An examination into the effect of using the new powder in the existing new type forged steel gun.

A few remarks on the influence of the new powder on the design of guns, and finally some general conclusions.

II.

NATURE OF THE POWDER—PRODUCTS OF COMBUSTION—POTENTIAL—FORCE—COMPARISON WITH OLD POWDERS.

15. The very remarkable results which have been recently obtained from smokeless powder in France and Germany, point to an entire revolution in artillery practice, as well as to a complete revision of the system of gun construction and the formulæ of internal ballistics.

16. M. Sarrau's formulæ of velocity and pressure, which are very approximately correct for charcoal powders, such as the ordinary black and brown powders, are no longer applicable to the case of the new powders which give much higher velocities with smaller charges and reduced pressures. This must consequently lead to modifications in the proportions of guns, if it be admitted that these proportions are dependent on the pressures existing in different portions of the gun.

17. The superior results obtained from the new powders are mainly due to the fact that, with them, nearly the whole of the powder is converted into permanent gases, whereas with the old powders only about 43 per cent. is so converted, the remaining 57 per cent. being inert matter existing in the gun in the form of a very finely diffused liquid, which, when cooled down, solidifies; and is not only mainly the cause of the smoke, but also in all probability one cause of the excessive erosion.

18. Although the chemical constitutions of the new powders are kept as secret as possible, they are probably all closely allied to that of Nobel's smokeless powder, that is to say, the main ingredients are nitro-cellulose and nitro-glycerine, to which is added nitrate or perchloride of ammonia and a little camphor.

19. An analysis of the reactions which take place on the explosion of this mixture is given in the Appendix A, and from this it appears that the whole of the products consist of permanent gases and watery vapour, the volume of which amounts to about 705 cubic centimetres for each gramme of powder.

20. Further, that the heat evolved, after allowing for the vaporisation of the water, is about 1·7143 French units per gramme of powder.

21. The mean specific heat of the products is found to be about ·1989, and their theoretic temperature about 8673° C.

22. Appendix B contains a similar examination of the results of combustion of pebble powder, which may be taken as a type of the old powders, from which it appears that the following are the results :—

Volume of gas from 1 gr. of powder ..	286 cm. cube.
Gramme units of heat	690·2
Mean specific heat	·187
Theoretic temperature of products ..	4750° C.

23. The temperatures above calculated may be called the "Theoretic or Potential Temperature." The actual temperatures are probably not more than one-half, owing partly to the cooling effect of the walls, and partly to the increase of the specific heat at the high temperature and pressure existing in a gun; but they probably represent the relative effect of the two powders as regards the temperature of the products of combustion.

24. The following comparison of the two powders may therefore be made :—

	Pebble.	Nobel's.
Volume of gas at 0° C. and ·76 metres from 1 gramme of powder	286	705
Gramme units of heat evolved from 1 gramme	690·2	1714·8
Mean specific heat of products	·187	·199
Theoretic temperature of products	4750°	8673°C.

Potential of Nobel's Powder.

25. By the "Potential" is meant the mechanical equivalent of the heat developed by the combustion of unit of weight of the powder, or E Q; when Q is the quantity of heat evolved, E = 436 in French unities, or 772 in English unities. Now it has been shown that Q = 1·714 units per gramme, or 1714 per kilogramme.

Therefore, Potential $= \frac{436 \times 1714}{1000} = 747 \cdot 3$ metre-tons per kilogramme, or 1095 foot-tons per lb. of powder.

26. In the treatise on 'Internal Ballistics'* (page 8), there is a table of the "Potentials" of various explosives, and that of pebble powder is given as 460 foot-tons per lb., or considerably less than the half of that of Nobel's powder; but, as was there observed, the "Potential" of an explosive must not be confounded with the mechanical effect which may be obtained from it, nor with the pressure developed by its combustion in a closed vessel.

27. At page 50, 'Internal Ballistics,' the symbol "f" was used to denote what is called by M. Sarrau, the "force" of the powder, and it was defined by the relation

$$f = \frac{p_0 V_0 T_0}{273},$$

where p_0 is the atmospheric pressure = 103·33 kilog. per square decimetre;

" V_0 is the volume of gases from unit of weight at temperature zero and atmospheric pressure;

" T_0 is the absolute temperature of combustion.

Taking the kilogramme as unit of weight, the volume of gas is, for Nobel's powder, 705 × 1000 cm.^{3} or 705 dm.^{3}

If the actual temperature of combustion be taken as one-half of the theoretic value, or 4326° C., the absolute temperature

$$= 4326 + 273 = 4599°.$$

* 'Internal Ballistics,' by J. A. Longridge. Spon, London, 1889.

Therefore $f = \dfrac{103 \cdot 33 \times 705 \times 4599}{273}$

$= 1{,}227{,}022$ kilogrammes per square decimetre.

The value of f for pebble powder is given at page 51, 'Internal Ballistics,' as 263,600, consequently the ratio of f, as between Nobel's powder and pebble, is $\dfrac{1227022}{263600} = 4 \cdot 655$.

28. The "force," f, as defined by M. Sarrau, is the absolute pressure of powder exploded in a close vessel entirely filled; that is to say of gravimetric density = 1, and with ordinary powder $p = f \dfrac{\Delta}{1 - a\Delta}$, where a is the proportion of non-gaseous matter, which, with ordinary powders, is about $0 \cdot 57$ of the weight. In Nobel's powder $a = 0$, consequently $p = f\Delta$ and if $\Delta = 1$, $p = f = 1{,}227{,}022 = 122 \cdot 7$ kilog. per mm.^{2} $= 78 \cdot 52$ tons per square inch, which is nearly double that of pebble powder.

29. It is therefore apparent that the Nobel powder is capable of producing much higher pressure than the pebble, and yet in practice it gives higher velocity with less charges and lower pressures.

This apparent paradox is easily seen to be due to the absence of inert matter, the whole of the powder being converted into gas, instead of only 43 per cent. as in pebble powder, and the total volume of gas being 705 cm.^{3} per gramme of powder, against 286 cm.^{3} for pebble, whilst at the same time the temperature of combustion is about double.

30. *Actual Pressure in gun.*—The actual pressures in guns are of course much below the calculated values of p, for two reasons: first, because there is a loss of temperature due to the cooling action of the chamber walls, and secondly, because by the time the whole of the charge is burnt, the projectile has moved a considerable way along the chase and so increased the space to be filled by the evolved gases.

If, for instance, there be a maximum pressure of 15 tons in

the gun (assuming for the moment that there is no loss of heat), we have

$$v = v_0 \left(\frac{p}{p_0}\right)^{1 \cdot 319},$$

and making

$$p = 78 \cdot 52, \text{ and } p_0 = 15,$$

we get

$$v = v_0 \times 3 \cdot 506;$$

so that, if the rate of burning of the powder were suitable, a full charge of gravimetric density = 1 might be fired, and yet the maximum pressure not exceed 15 tons per square inch, which would be attained when the projectile had moved 3·506 times the length of the charge along the chase.

31. Another advantage will probably be the absence of fouling, as the whole of the matter is converted into gases, which leave little or no residuum in the gun.

32. *Erosion.*—As regards erosion, experience must decide. But it may be said that on the one hand, the products of combustion being entirely gaseous, instead of a mixture of gas and fluids, will probable erode less; whilst on the other hand that the increased temperature and volume will tend to augment that erosion.

With the new powder, the temperature no doubt falls more rapidly than with the ordinary powder, because the loss of heat being a function of the difference of temperature between the gases and the gun, is greater with high temperatures; whilst on the other hand, with ordinary powder, it is quite possible that whilst the guns are expanding, heat is communicated to them from the highly heated liquid, arising from the non-gaseous portion of the charge diffused through them. The question of erosion must therefore be determined by experience. So far as our present knowledge goes, the smokeless powder in this respect appears to possess the advantage.

III.

BALLISTIC EFFECT OF NEW POWDERS IN FRENCH AND GERMAN GUNS—COMPARISON OF B.N. AND NOBEL'S POWDER.

33. *Formulæ for Pressure and Velocity.*—It is not surprising that the formulæ which represent the ballistic action of the old powders are found to be inapplicable to the new powders, and although it is probable that M. Sarrau has already so modified his formula as to make it represent the action of the new powder, it is scarcely likely that the results of his investigations will be made public at present.

34. Although the experimental data published are very limited, it will not be without interest to examine them carefully. These data are contained in notices of results of firing, obtained at Essen in July and August 1889, with Nobel's powder fired from four different guns, and of the results obtained from the French B.N. powder fired from 10 cm. and 15 cm. guns, or 3·937 and 5·90 inches calibre respectively.

35. An examination of these results leads to a rather remarkable conclusion, which, however, must be taken with all reserve.

It is as follows:—

1st. The muzzle velocity of the projectile is proportional to the $\frac{3}{4}$th power of the weight of charge.

2nd. The maximum pressure in the gun is proportional to the square of the weight of the charge.

$$V = A\,w^{\cdot 75} \qquad (1)$$
$$P = B\,w^2. \qquad (2)$$

The coefficients A and B are not constants, but are composed

of various factors, which are functions of the form, dimension, and rate of burning of the grain—in fact, what are called by M. Sarrau the "characteristics of the powder—of the weight of the projectile, the calibre of the gun, and the length of travel of the projectile.

In M. Sarrau's formula, he introduces another factor Δ, the gravimetric density, but this is in itself a function of the weight of charge, and of the calibre of the gun.

Taking, for instance, M. Sarrau's monomial formula for velocity, as given at page 98, 'Internal Ballistics,'

$$V = H \, . \, \frac{w^{\frac{3}{8}} \, \Delta^{\frac{1}{4}} \, l^{\frac{3}{16}} \, c^{\frac{1}{8}}}{W^{\frac{7}{16}}},$$

where H is a factor containing the "force" and "characteristics" of the powder;

w = weight of charge;
Δ = gravimetric density;
l = length of travel of projectile;
W = weight of projectile;
c = calibre of gun.

Now, if λ = equivalent length of chamber,

$$\Delta = \frac{\text{weight of charge}}{\text{capacity of chamber}} = \frac{w}{\cdot 7854 \, c^2 \, \lambda};$$

substituting which in the above we get

$$V = \left\{ \frac{H}{(\cdot 7854)^{\frac{1}{4}}} \cdot \frac{l^{\frac{3}{16}}}{c^{\frac{3}{8}} \, l^{\frac{1}{4}} \, W^{\frac{7}{16}}} \right\} w^{\frac{5}{8}} \qquad (3)$$

and it is the part within the bracket that is represented by A in (1).

In like manner Sarrau's formula for pressure is

$$P_0 = K_0 \, a^2 \, \frac{\Delta \, w^{\frac{3}{4}} \, W^{\frac{1}{4}}}{c^2},$$

by substituting $\dfrac{w}{\cdot 7854\, c^2 \lambda}$ for Δ becomes

$$P_0 = \left\{ \frac{K_0\, a^2\, W^{\frac{1}{4}}}{\cdot 7854\, c^4\, \lambda} \right\} w^{1 \cdot 75} \qquad (4)$$

and the part within the bracket represents the B in (2).

36. From this it appears that in passing from the old to the new powders, the index of w is increased from $\frac{5}{8}$ to $\frac{3}{4}$ in the expressions for velocity; and from 1·75 to 2 in that for pressure, an increase which might be anticipated from the absence of inert matter in the products of combustion of the new powders.

The coefficients A and B of course are different with different guns, and different brands of powder.

37. The results of the experiments made at Essen in 1889 have been published in the 'Revue d'Artillerie,' vol. xxxv. These experiments were made with Nobel's powder fired from four different guns, the details of which are given in the following Table, No. I.

TABLE I.

	Number of Gun.			
	I.	II.	III.	IV.
Calibre in inches	1·968	2·362	2·984	3·287
Length of gun in calibres	40	40	28	40
Weight of gun .. .. lbs.	490	862	904	2310
,, of charge .. .. ,,	0·66 to 0·80	0·66 to 1·21	0·66 to 1·17	2·20 to 3·54
,, of projectile .. .. .. ,,	3·81 to 4·10	6·84 to 6·86	15	15·5 to 17·84

From the results obtained at Essen the following Tables II. and III. have been constructed.

Table II. gives the value of the coefficients A and B of formula (1) and (2) (§ 35).

Table III. gives the velocities and pressures, calculated

with these coefficients employed in formulæ (1) and (2), and compared with the results actually obtained at Essen.

TABLE II.

No. of Gun.	Number of Rounds Fired.	Size of Grain of Powder.	Weight of Charge.	Weight of Projectile.	Coefficients.	
					A.	B.
		in.	lbs.	lbs.		
I.	4	·1378	·66 to ·80	3·81	2560	20·0
	5	·1181	·66 to ·792	4·10	2455	20·5
II.	2	·1969	1 to 1·20	6·86	1527	5·79
	3	·1181	1 to 1·10	6·86	1880	10·20
III.	10	·1181	·66 to 1·17	15	1429	10·20
IV.	6	·1969	2·2 to 3·74	15·5	879	0·885
	4	·1557	3·3 to 3·54	17·84	920	1·215
	2	·1181	3·3	17·84	911	1·215
	2	·1181	3·286	17·84	986	1·760

TABLE III.

No. of Gun.	Round ..	1	2	3	4	5	6	7	8
	VELOCITY—Feet per Second.								
I.	Observed	1886	2089	2171	1798	2014	2070		
	Calculated	1887	2104	2165	1797	2018	2077		
II.	Observed	1637	1758	1109	1860	2043			
	Calculated	1640	1761	1109	1890	2019			
III.	Observed	1086	1188	1283	1417	1517	1591		
	Calculated	1047	1174	1284	1429	1535	1607		
IV.	Observed	1607	1883	2004	2136	2234	2336	2231	2168
	Calculated	1588	1821	2044	2151	2259	2364	2231	2166
	PRESSURES—Tons per Square Inch.								
I.	Observed	8·46	8·96	13·23	9·72	11·33	13·03		
	Calculated	8·71	11·83	12·80	8·94	12·16	13·12		
II.	Observed	6·89	8·60	3·12	„	10·18	12·48		
	Calculated	7·00	8·47	3·10	„	10·20	12·34		
III.	Observed	5·76	7·08	8·60	10·50	12·35	13·36		
	Calculated	4·44	6·65	7·90	10·20	11·77	13·96		
IV.	Observed	5·33	8·43	9·02	9·25	11·20	11·69	13·24	14·35
	Calculated	4·28	6·17	8·41	9·63	10·96	12·30	13·23	14·40

French Experiments.

38. The experiments made with the French smokeless powder B.N. were made with two of Canet's quick firing guns of (10 cm.) 3·937 inch and (15 cm.) 5·905 inch calibre, each of 48 calibres in length.

This is the total length of gun over all, the length of travel of the projectile being about 38 calibres.

The powders used were all of the description called B.N. In the 3·937 inch gun, three different lots were used, which may account for the difference of the coefficients A and B, whilst in the 5·905 inch gun the powder was of the same brand throughout.

39. Table IV. gives the values of A and B, and Table V. the comparison of the observed with the calculated ballistic results, corresponding with Tables II. and III. for the Nobel powder.

TABLE IV.

Gun Calibre.	Number of Rounds Fired.	Size of Grain unknown.	Weight of Charge.	Weight of Projectile.	Coefficients.	
					A.	B.
in.			lbs.	lbs.		
3·937	6	Lot 1	5·28 to 8·58	28·6	526	·2314
"	4	Lot 2	7·93 to 8·16	28·6	526	·2807
"	5	Lot 3	7·93 to 9·92	28·6	470	·1847
5·905	9	Lot 4	17·64 to 33·08	89·0	198	·0172

TABLE V.

Gun.	Round.. ..	1	2	3	4	5	6	7	8	9
ins.										
	VELOCITY—feet per second.									
3·937	Observed	1834	2001	2238	2434	2562	2628			
Lot 1	Calculated	1829	2057	2273	2431	2586	2637			
3·937	Observed	2490	2555	2582	2559					
Lot 2	Calculated	2482	2574	2591	2540					
3·937	Observed	2237	2355	2536	2615	2605				
Lot 3	Calculated	2221	2405	2539	2627	2627				
5·905	Observed	1666	1962	2303	2428	2603	2674	2671	2750	2746
	Calculated	1716	2008	2325	2470	2611	2680	2680	2750	2750
	PRESSURES—tons per square inch.									
3·937	Observed	6·54	8·79	11·34	14·20	15·88	16·83			
Lot 1	Calculated	6·45	8·78	11·47	13·72	16·17	17·04			
3·937	Observed	17·65	17·97	19·62	18·16					
Lot 2	Calculated	17·65	19·47	19·71	18·73					
3·937	Observed	11·75	13·50	16·64	18·10					
Lot 3	Calculated	11·62	14·37	16·60	18·17					
5·905	Observed	4·13	6·22	11·77	13·66	16·76	16·83	17·34	18·41	18·54
	Calculated	4·83	8·36	12·00	14·18	16·38	17·56	17·56	18·81	18·81

40. From these tables it appears that the formulæ (1) and (2), above given, represent very closely the results obtained by experiments, and it is therefore probable that the indices 0·75 and 2·0 denote the relations between the weight of the charge and the velocity and pressure respectively, at any rate it is so in these guns.

41. A comparison may be made between the French B.N. and the Nobel powder, first as regards the energy of the projectile per lb. of powder, and second as regards the energy per ton weight of gun.

For this purpose take the (10 cm.) 3·937 inch Canet gun, weighing 4620 lbs., and compare it with the 3·287 inch Krupp gun, weighing 2310 lbs.; the Canet gun being fired with B.N., and the Krupp gun with Nobel's powder of ·1557 inch size of grain.

It is assumed that the strain on the two guns is the same, that is to say, that the charge shall be such as will give the same maximum pressure in the two guns, and that this pressure shall be 18·17 tons per square inch, as in the fourth round of this gun in Table V., giving a velocity of 2615 foot-seconds.

Therefore, in the Canet gun,

$$\text{Energy} = \frac{2615^2 \times 28\cdot5}{64\cdot4 \times 2240} = 1355 \text{ foot-tons};$$

which gives

Energy per ton of gun 657·1 foot-tons,
 ,, per lb. of powder 136·7 foot-tons.

42. In the 3·257 inch Krupp gun, in order to give the pressure of 18·17 tons, the weight of charge of the ·1557 inch grain Nobel powder is found by the equation $P = 1\cdot215\, w^2$, whence

$$w = \sqrt{\frac{18\cdot17}{1\cdot215}} = 3\cdot867 \text{ lbs.},$$

and the velocity with this charge would be

$$V = 920\, w^{\cdot75} = 2537 \text{ feet per second};$$

therefore

$$\text{Energy} = \frac{2537^2 \times 17 \cdot 84}{64 \cdot 4 \times 2240} = 795 \cdot 8 \text{ foot-tons,}$$

which gives

Energy per ton of gun $= 771 \cdot 7$ foot-tons.
„ per lb. of powder $= 205 \cdot 8$ „

43. If the powder of $0 \cdot 1969$ inch grain were used, the requisite weight of charge would be $4 \cdot 531$ lbs., and the velocity 2730 feet per second, giving the Energy of the 15 lb. projectile $= 774 \cdot 7$ foot-tons, which gives

Energy per ton of gun $= 751 \cdot 2$ foot-tons.
„ per lb. of powder $= 171 \cdot 0$ „

44. These results are brought together for comparison in the following Table.

TABLE VI.

	3·937 inch Gun. B.N. Powder.	3·287 inch Gun. ·1557 inch Nobel.	3·287 inch Gun. ·1969 inch Nobel.
Total energy	1355	795·8	774·7
Energy per ton of gun	657·1	771·7	751·2
Energy per lb. of powder ..	136·7	205·8	171·0

45. The results show somewhat in favour of the Nobel powder, both per ton of gun and per pound of powder.

46. It must further be observed that the $3 \cdot 937$ inch gun has the advantage over the $3 \cdot 287$ inch gun, in being a gun of 48 calibres as against 40 calibres in the latter. If the guns had been what is termed "similar guns" and similarly loaded, the velocities would have been the same, but the weight of projectiles as the cubes of the calibres, consequently the energy of similar guns increases as the cube of the calibre, which in the present case is in the ratio

$$\left(\frac{3 \cdot 937}{3 \cdot 287}\right)^3 = 1 \cdot 719.$$

Consequently, had the guns been similar and similarly loaded, the total energy would have been

$$\text{as } 1355 : 788{\cdot}5;$$

so that not only is the energy of the smaller gun greater than the due proportion, but this is the case under the disadvantage of being the shorter gun.

47. So far then as these experiments go, it appears that the Nobel powder is superior in ballistic power to the B.N. powder.

IV.

PRESSURES IN THE CHASE WITH NEW POWDER—COMPARISON WITH PRESSURES FROM PEBBLE POWDER.

48. In the absence of further experimental data it is impossible to deduce the relations between the velocity and pressure and the other ballistic elements, such as the length of travel of projectile, weight of projectile, and calibre of the gun, so that the coefficients A and B given above can only be made use of for "similar" guns.

49. It is very important to ascertain as far as may be possible, the distribution of pressures along the chase whilst the projectile is travelling to the muzzle.

50. As has already been shown, there is reason to believe that in a close vessel impermeable to heat, the pressure from the new powder would be about double of that given by the old black powder. Consequently, as in practice the maximum pressure is not greater, it follows that the rate of combustion must be slower, thus giving more time for the projectile to get out of the way, and by thus increasing the space, keep down the pressure.

It is also quite possible that the combustion may go on for a considerable time after the maximum pressure is attained, and that thus the pressures towards the muzzle may be greater than with the ordinary powders.

51. As this is a point of great importance relative to the designing of guns, the question requires examination, so far as the limited experience available enables it to be done.

52. Consider the case of the (15 cm.) 5·905 inch Canet

Q.F. 15 cm. gun of 48 calibres with B.N. powder, of which the following are the ballistic elements:—

CANET'S Q.F. 15 CM. GUN.

Calibre of gun		5·905 inches.
Length of travel of projectile ..		224·5 ,,
Equivalent length of chamber ..		53 ,,
Capacity of chamber		1500 cubic inches.
,, of chase		6174 ,,
Total capacity of gun		7674 ,,
Number of expansions $\frac{7674}{1500}$	=	5·116
Weight of charge		33·08 lbs.
Weight of projectile		89 ,,
Weight of gun		6·29 tons.
Muzzle velocity		2750 f.s.
Total energy $\frac{2750^2 \times 89}{64\cdot4 \times 221\cdot0}$	=	4665 foot-tons.
Energy per ton of gun		744·6 ,,
,, per lb. powder		141·0 ,,
Maximum pressure		18·81 tons per sq. in.

53. First, it may be asked, what must have been the mean pressure in the gun? The total energy expended on the projectile was 4665 foot-tons, to which must be added that expended in overcoming friction and expelling the gases, &c. This may be estimated at an additional 20 per cent., making the total energy 5598 foot-tons.

Now the area of section of the projectile is 27·4 inches, and the travel 18·4 feet. Therefore, if p be the mean pressure,

$$p = \frac{5598}{27\cdot4 \times 18\cdot4} = 10\cdot92 \text{ tons per square inch.}$$

54. Next, if it be granted that the pressure in a close vessel would be 78·53 tons per square inch, and that the products of combustion act as a perfect gas, it may be inquired, at what point in the travel of the projectile will the pressure be reduced to the maximum pressure of 18·81 tons? This can only be approximately ascertained in the absence of

knowledge as to the loss of heat due to cooling, but from the considerations set forth in 'Internal Ballistics,' Chapter V., it would appear that this is not very great. Leaving this loss out of account, there is the relation $\frac{p_0}{p} = \left(\frac{v}{v_0}\right)^{1\cdot319}$, where p_0 and v_0 are the original and p and v the final pressures and volumes, and as the volumes are proportional to the lengths, the relation becomes $\frac{p_0}{p} = \left(\frac{l}{l_0}\right)^{1\cdot319}$. Now let l_0 be the length of the bore which would be occupied by the charge at gravimetric density = 1, and l the distance from the breech at which the pressure is reduced to $p = 18\cdot81$, then

$$l = l_0\left(\frac{p_0}{p}\right)^{\frac{1}{1\cdot319}} = l_0\left(\frac{78\cdot52}{18\cdot81}\right)^{\frac{1}{1\cdot319}}.$$

55. For ordinary powder the space occupied at gravimetric density = 1, is 27·7 cubic inches per lb. or 1 decimetre cube per kilogramme, and when the charge is thus spaced it is said to be of gravimetric density equal unity. If, however, the space be any other number, say 30 inches to the lb., the gravimetric density is said to be

$$\frac{27\cdot7}{30} = 0\cdot923.$$

56. It is as well to observe, however, that, with the French, "densité gravimétrique" has a different meaning.

"Densité gravimétrique" is the weight of 1 cubic decimetre of powder, not pressed together except by its own weight. Consequently it is evident that the "densité gravimétrique" of a given powder is dependent partly on its absolute density, i. e. specific gravity, and partly on the size of the grain. For instance, the French powder F_1 has an absolute density of 1·750, whilst its gravimetric density is ·830 to ·870, whilst the $W\frac{13}{30}$, which has nearly the same absolute density, has a gravimetric density of 1·03 to 1·17.

The equivalent of "gravimetric density" in French is not "densité gravimétrique," but "densité de chargement."

57. As is well known, with the ordinary old powders 27·7 cubic inches is the space occupied by 1 lb. of powder. But this is not so with the new powder. With respect to this there is much reticence. It is, however, probable that 1 lb. of this powder may occupy about 31 cubic inches of space, and it is on this assumption that the following remarks are made. Though the conclusions arrived at may not be quite correct, yet they will be relatively so, and will therefore be useful in the examination of the ballistic properties of the new powder.

58. Assuming, then, that the space occupied by 1 lb. of powder is 31 inches, the length of bore l_0 occupied by the charge is easily determined.

The charge being 33·08 lbs., and the area of the bore 27·4 inches, we get

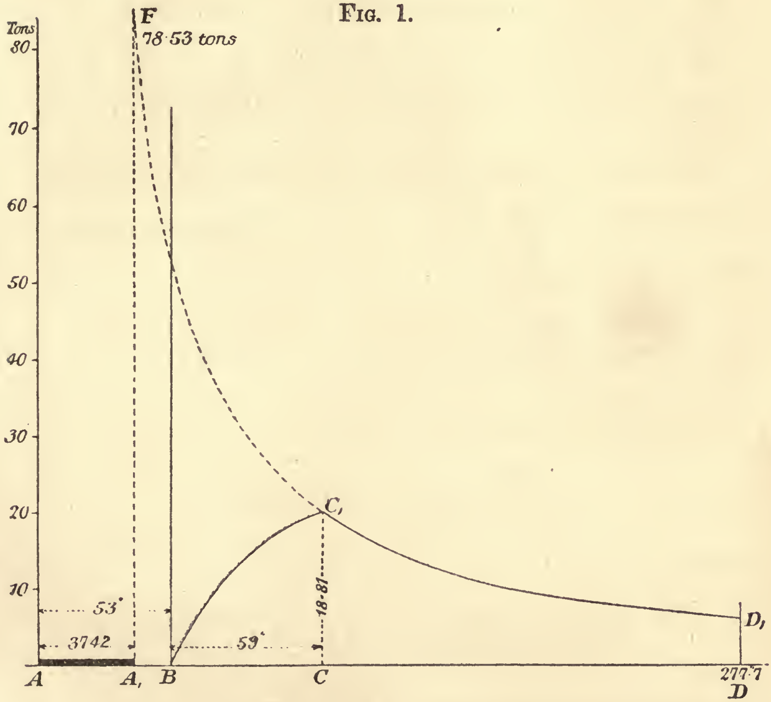
$$\text{Length} = \frac{33 \cdot 08 \times 31}{27 \cdot 4} = 37 \cdot 42 \text{ inches.}$$

59. Let, then, A D (Fig. 1) represent the bore of the gun' A B the "equivalent length" of the chamber, that is to say, a length of bore whose capacity is the same as that of the chamber, and B D the travel of the projectile, and let A A be the length of the bore which would be occupied by the charge at gravimetric density = 1, that is to say, in the present case 37·42 inches. Then, if the powder were fired in a close vessel, the pressure would be 78·53 tons per square inch; but as the projectile moves away the space increases, and the contest between the evolution of gas and the increasing space goes on until a maximum pressure is reached. If it be assumed that all the powder is burnt at this time, the point C_1, on the curve F C_1 D, corresponding to this maximum pressure, will denote the position of the projectile, and the ordinates between C and D the respective pressures on the bore as the projectile moves to the muzzle; the curve F C_1 D being calculated from the formula

$$p = p_0 \left(\frac{l_0}{l}\right)^{1 \cdot 319}.$$

The ordinates between B and C* are indeterminate, and depend upon the rate of evolution of the gas, the weight of projectile and other elements, but it may be assumed that approximately the pressure curve is represented by the curve B C_1 D_1 D, and that the point of maximum pressure is at C_1,

Fig. 1.



and that the total work done on the projectile is represented by the area of the curve multiplied by the area of the bore of the gun.

60. Taking the unit for abscissa in feet, and for the ordinate in tons per square inch, the area of the curves A C_1 D_1 D is found to be 210·2, which is the foot-tons per square inch of

* The assumption that the curve from B to C_1 is one-fourth of an ellipse has been found by the author to give very satisfactory results.

bore; and multiplying this by 27·4 the area of the bore gives 5761 foot-tons. If from this be deducted 20 per cent. for the resistance, friction, and expulsion of the gases, there remains 4629 foot-tons for the energy of the projectile.

This was found by experiment to be 4665 foot-tons.

It may therefore be concluded that the pressure curve (Fig. 1) represents, approximately, the pressure in the gun with a 33 lb. charge of the new powder.

61. Let now this be compared with the corresponding diagram of the same gun fired with a full charge of pebble powder.

The capacity of the chamber being 1500 cubic inches, the full charge will be $\frac{1500}{27\cdot 7}$ = 54 lbs., which, as is shown in Appendix C, gives

Muzzle velocity	2570 feet per sec.
Pressure on projectile	22·00 tons.

Therefore the energy is

$$\frac{2570^2 \times 89}{64\cdot 4 \times 2240} = 4073 \text{ foot-tons,}$$

which gives

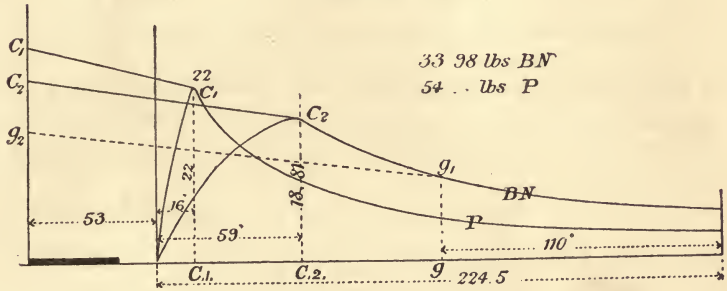
Energy per ton of gun	650·2 foot-tons.
" per lb. of powder	75·43 "

62. The following Table shows the comparison between the B.N. and pebble powders in the 5·90 inch gun.

Powder.	Weight of Charge.	Weight of Projectile.	Muzzle Velocity.	Maximum Pressure on Projectile.	Total Energy.	Energy.	
						Per Ton of Gun.	Per Lb. of Powder.
	lbs.	lbs.	feet per second.	tons per sq. in.	foot-tons.		
B.N. ..	33·08	89	2750	18·81	4665	744·6	141·0
Pebble ..	54·00	89	2570	22·0	4073	650·2	75·43

63. If a pressure curve be constructed for the pebble powder in the same manner as above described, and superimposed upon the curve for the charge of 33·08 lbs. of B.N. as in Fig. 2, the difference in the distribution of pressure is very strikingly seen.

Fig. 2.



64. The maximum pressure on the base of the projectile is 18·81 tons per square inch with the B.N., and 22 tons with the pebble powder, but the position at which it attains its maximum is when the shot has travelled 59 inches in the first case, against 16 inches in the second.

Again, the final pressure is 5·65 tons per square inch with the B.N., against 3·1 tons with the pebble powder.

V.

EFFECT OF THE NEW POWDER ON EXISTING GUNS.

65. Enough has now been said to show that the new powder is a revolutionary element in ballistic practice, and that it must consequently exert a corresponding influence on gun construction.

66. It is therefore very important to examine what will be the effect of using such powder in the present new type steel guns, which were designed for the older powders, such as the black and brown prismatic, and the still later E.X.E. powder.

67. These powders are characteristically weak powders, that is to say, they burn slowly and give low pressures in guns. The effect is made up by largely increasing the charges, and in order to give time for the entire combustion and also for utilising the expansive force of the gases, the guns are made very long.

In order to contain the large charges and also to reduce the length of the gun, enlarged powder chambers are adopted, with, however, the disadvantage of increasing the size of the breech mechanism, and the strain upon it.

68. Now, in the first place, it may be asked what will be the effect of using the new powders on these guns? It is claimed for the new powders that, in addition to their quality of smokelessness, they will give vastly higher ballistic results, while they will strain the gun less owing to their low maximum pressure, and this statement has been used as an argument against the necessity of adopting wire guns, instead of the usual forged steel construction.

68*a*. It is not intended to enter here into the questions of the relative cost of production, the greater freedom from

latent defects, the quicker production, or the relative facilities of repairs, in all which respects the wire system has undoubted advantages. But it is desired to show that, *if the full advantage is to be obtained from the high ballistic properties of the new powder, it can only be obtained by the use of comparatively high pressure, and consequently, very strong guns, such as can only be produced by the wire system of construction.*

69. It is argued that the advantages of the new powders may be utilised in two ways.

70. Either by retaining the present initial velocity with the benefit of a great reduction of pressure, or on the other hand by retaining the present maximum pressure of about 16 tons per square inch, and thus obtaining a very great increase of velocity, although admittedly retaining the disadvantage of a great length of gun.

71. The former alternative is thought to be the better for field guns, as they cannot be lengthened without increase of weight, which is inadmissible. Morever, the weight of cartridges could thus be reduced, consequently more of them could be carried; whilst it has also been said that, as the pressures are reduced, the strain on the gun carriage would be relieved.

72. This last assertion is, however, a mistake. The effect of the strain on the carriage is proportional to the work done on it, and this varies as the square of the velocity of recoil, which velocity, *cæteris paribus*, is in proportion to the velocity of the projectile, and has nothing to do with the pressure by which that velocity is created.

Consequently, if the muzzle velocity be unchanged the strain on the carriage must be the same, and if, by the use of the new powder, the velocity be increased, the strain on the carriage must be increased correspondingly.

73. This is of course slightly modified by the fact that, in calculating the velocity of recoil, a portion of the weight of the charge must be taken into account, as well as the weight of the projectile, but the effect of this will be comparatively

small, and in the case of increased velocity of the projectile, will be far less than the increase due to the increased velocity of the projectile, which is not a function of the maximum pressure, but depends on the mean pressure, which is quite another thing.

74. As regards the length of gun required for the new powder, it is argued that by increasing the pressure it would be necessary also to increase the length of the gun to a practically impossible extent.

75. But this also is erroneous, for it apparently rests on the assumption that the maximum pressure can only be increased by increasing the weight of charge, and that unless the length of the chase be correspondingly increased, part of the charge will be blown out of the muzzle unburnt.

76. Now the maximum pressure depends, not altogether, nor indeed principally, on the weight of the charge, but is chiefly affected by the rate of evolution of the gas, which is regulated almost *ad libitum* by modifying the form and size of the grain.

It is therefore quite practicable to increase the maximum pressure, even if the weight of charge be diminished.

77. This will be the more evident after the following examination of the action of the powder in a gun.

78. In the first place, reverting to Fig. 2 which shows the pressure in the same gun when fired with charges of 33·08 B.N. and 54 lbs. P respectively; in order to complete the curves the pressures behind the points of the maximum must be indicated.

79. According to M. Sarrau's formulæ for ordinary powder, if P_0 be the pressure on the breech, P the maximum pressure on the base of the projectile, making use of English unities of pounds for weight and tons per square inch for pressure,

$$P_0 = 1 \cdot 94 \, . \, P \left(\frac{w}{W}\right)^{\frac{1}{4}},$$

w and W being the respective weights of charge and projectile.

Another formula which is said to give better results, especially with slow powders, is

$$P_0 = P \frac{W + \frac{w}{2}}{W}.$$

80. Making use of this latter formula and the weights corresponding to Fig. 2, we find

$$\text{For B.N. powder } P_0 = P \frac{105 \cdot 5}{89} = 1 \cdot 19 \text{ P.}$$

$$\text{For pebble ,, } P_0 = P \frac{116}{89} = 1 \cdot 30 \text{ P.}$$

From which the breech pressures corresponding to the maxima in the diagrams are 22·38 and 28·6 tons respectively.

Setting off these ordinates at the breech the line C_2C_1 represents the internal pressure in the gun when the projectile is at C_1, and a line parallel to it, such as $g\, g_2$, represents the pressure when the projectile is at any other part g.

81. What is most important to note is that whilst the maximum pressure is considerably less with the B.N. powder, although the work done is nearly 15 per cent. more, and the powder charges 40 per cent. less, the pressures are thrown so much further forward, that the B.N. powder if fully utilised will require a very differently proportioned gun, one, namely, in which there is about the same strength behind the point of maximum pressure, but very much greater strength in front of it.

82. Taking for instance the point g_1, Fig. 2, at 110 inches from the muzzle, the pressure to be resisted will be 10½ tons per square inch with the B.N. powder, as against 5½ tons with the pebble.

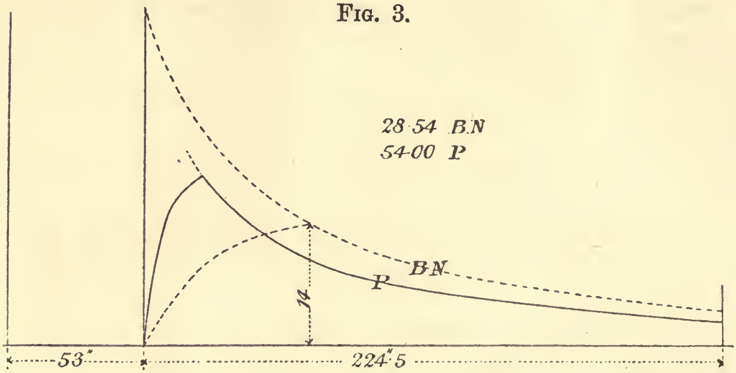
83. It is quite true that this pressure may be reduced by reducing the charge of the B.N. powder.

84. If, instead of firing with 33·08 lbs., the charge was reduced to 28·52 lbs., the velocity would be the same as that given by the 54 lbs. of pebble powder, and the maximum

pressure would be reduced to 14 tons per square inch. The length of charge would be 30 inches of the bore.

85. The dotted curve, Fig. 3, is constructed from these data, and being superimposed on the diagram for 54 lbs. of pebble powder, shows the respective action of the two

FIG. 3.



powders in the same gun, while producing the same ballistic effects.

86. It is evident that a gun designed to sustain the pressures of the pebble powder is insufficient in strength to sustain the pressures of the new powder in all that part of the chase commencing at about 180 inches from the muzzle.

87. To elucidate this, let an examination be made of the Royal Gun Factory 6[a] B.L. gun, MARK IV. of the following ballistic elements :—

Calibre	6 inches.
Length of rifling	127 „
Capacity of chamber	1364 cube inches.
Equivalent length of ditto	47·03 inches.
Total capacity of gun	5105 cube inches.
Expansions	3·743.
Charge E.X.E.	48 lbs.
Weight of projectile	100.
Muzzle velocity	1980 feet per second.
Maximum pressure	16·50 tons per sq. in.

88. In order to compare this gun with the 15 cm. Canet gun, it must first be considered on the supposition that it is lengthened so as to make the travel of the shot the same, viz. 224·5 inches, and then determined what would be the muzzle velocity with the same charge of 48 lbs. of E.X.E. powder but with a projectile of 89 lbs.

89. From such data as are at the author's disposal it appears that the "characteristics" of the E.X.E. powder are

$$\text{Log}\,\alpha = \cdot 06136$$
$$\text{Log}\,\beta = -1\cdot 47844$$

Making use of which in Sarrau's binomial formulæ for velocity gives

$$V = 2444 \text{ feet per second.}$$

90. This is the velocity which is taken as a basis of comparison with the Canet gun fired with B.N. powder.

Now, by formula (1)

$$V = 198\, w^{\frac{3}{4}},$$

and making V = 2444 gives

$$w = 28\cdot 52 \text{ lbs.}$$

Then by formula (2)

$$P = \cdot 0172\, w^2,$$

which making $w = 28\cdot 52$ gives

$$P = 14 \text{ tons per sq. inch}$$

for the Canet gun.

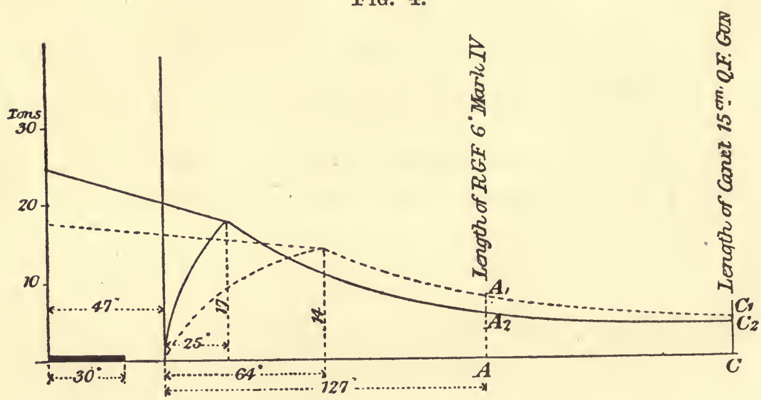
The comparison is therefore as follows:—

	Charge.	Projectile.	Muzzle Velocity.	Maximum Pressure.
	lbs.	lbs.	feet per second.	tons.
Canet 15 cm. gun	28·52 B.N.	89	2444	14·0
R.G.F. 6 in. Mark IV. lengthened	48 E.X.E.	89	2444	16·5

Thus, with $2\frac{1}{2}$ tons less pressure the Canet gun only requires about $\frac{7}{12}$ of the charge required of E.X.E.

91. It remains, however, to be seen how the variations of pressure throughout the chase take place in the two guns, and for this purpose recourse must be had to pressure curves, obtained as above described. These, though not accurately correct, represent approximately the real pressures. The curve for the E.X.E. powder is obtained by making use of the formula given in 'Internal Ballistics,' page 172, with

Fig. 4.



allowance of 20 per cent. for resistance, and is represented by the full line in Fig. 4.

92. The curve for the B.N. powder is obtained as follows:—The charge of $28 \cdot 5$ lbs. at gravimetric density $= 1$ would occupy $28 \cdot 5 \times 31 = 883$ cubic inches, which is equal to 30 inches of the bore, and the initial pressure in this space would be $78 \cdot 52$ tons per square inch. Therefore the equation to the curve is

$$p = 78 \cdot 52 \left(\frac{30}{l}\right)^{1 \cdot 319},$$

from which the curve represented by the dotted line, Fig. 4, is constructed.

Placing the two curves over each other. as shown in the

figure, it is seen that, although the maximum pressure of the B.N. powder is 3 tons less than that of the E.X.E., yet it is thrown about 39 inches further forward, and that at this point the pressure is about 4 tons per square inch greater than it is with the E.X.E. at the same point in the gun.

93. To pass from this to the Mark IV. gun of the actual length, it is sufficient to cut off from the diagram the excess of length in front of A; the length up to A being that of the travel of the shot with Mark IV. gun, viz. 127 inches. Then, by subtracting the areas $A\,A_1\,C_1\,C$ and $A\,A_2\,C_2\,C$ from the original areas of the two curves, the remaining areas represent the work done in the two guns if reduced to the length of the actual Mark IV. gun.

The original areas are 4537 for each, and the deductions 1299 and 1032; therefore the remaining areas are 3238 and 3505 respectively, representing the energies of the two guns corresponding to muzzle velocities of 2049 and 2132 feet per second.

94. From this it follows that with the R.G.F. 6-inch Mark IV. gun and a projectile of 89 lbs. nearly the same velocity would be obtained from 28½ lbs. of B.N. as from 48 lbs. of E.X.E., and that with 3 tons per square inch less maximum pressure. But this maximum would be about 39 inches nearer the muzzle.

95. Let it now be inquired how the new distribution of pressure would affect the Mark IV. gun?

It may be assumed that this gun has no *superfluous* strength, especially in front of the trunnions; indeed, evidence is not wanting to show that the strength of existing guns is deficient rather than excessive in this respect.

But let it be assumed that the present strength is suitable for the pressures developed by a full charge of 48 lbs. E.X.E. powder.

96. Let the strength of the gun be examined at two points, one at 64 inches, the other at 32 inches from the muzzle. At the first point the gun consists of the A tube 1·75 inch thick, and the B_1 tube 1·385 inch thick.

At the second point it consists of the A tube, 1·35 inch thick, and the B_1 tube, 1·25 inch thick.

97. According to the principles laid down in the Official Treatise on the Manufacture of Ordnance, 1886, no gun is allowed to be strained beyond three-fourths of the elastic limit of the material, which is fixed at 15 tons per square inch for the A tube, and 18 tons for hoops or the B tube.

Consequently the allowed strain is $15 \times \frac{3}{4} = 11{\cdot}25$ tons for the A tube, and $18 \times \frac{3}{4} = 13{\cdot}50$ tons for the B tube.

98. Making use of the above dimensions, it will be found by the usual formula that the greatest permissible pressure is 9·665 tons per square inch at 64 inches from muzzle, and 6·983 tons per square inch at 32 inches from muzzle.

99. Now, with the E.X.E. powder the pressures at these points are about 10 tons and 8 tons per square inch respectively, so that the gun nearly answers to the required conditions; but with the B.N. powder the pressures would be 14 tons and 10 tons per square inch respectively, an excess of $4\frac{1}{3}$ tons in the first case and about 3 tons in the second.

100. It is therefore manifest that the strength of this gun in the chase is quite insufficient for a charge of 28·52 lbs. of B.N. powder, and any less charge would give a less ballistic result.

101. It may be objected that the dotted curve Fig. 4 is theoretical, and not based on actual observation, except as regards the maximum pressure, and that the actual results of firing have not shown the guns to be too weak.

102. With regard to the last objection, it has not much weight. A gun may go on firing for a greater or less time without bursting or any visible damage, but not the less surely is it injured every time that it is strained beyond the elastic limit, and this seems to be fully admitted at Woolwich, where, as stated in the Official Treatise, the practice is to limit the maximum strain to three-fourths of the elastic limit. If, therefore, the present guns are not too strong for the present powder, and if the pressure curves be even

approximately correct, the guns cannot safely be used with the new powder with increased ballistic effect.

103. The objection against the curve as theoretical carries more weight. Not only is it theoretical, but it depends on the assumption of the pressure in a close vessel being 78·52 tons per square inch.

The reason for this assumption is given above, and there is nothing in it which appears either improbable or inconsistent with such other facts as are known with respect to this powder.

The law of decrease of pressure by which the ordinates and the curves are calculated is a rational law, and in all probability approximately true for the powder gases.

104. Moreover, the velocities deduced from the area of these curves (due allowance being made for other resistances) agree very well with the observed velocities, and consequently, whatever be the real form of the pressure curve, its area must be approximately the same as that of the dotted curve, Fig. 4.

105. In the next place, the final ordinate at the muzzle must be the same (if all the charge is consumed), but it is quite possible that the point of maximum pressure may be further to the rear than shown in the curve, Fig. 4.

Indeed, the curve may possibly be of such a form as shown in Fig. 5, A B C, the area of which may be the same as that of A B_1 C. Even in this case the pressures in front of the chase must be greater than with the other powder.

It may also be observed that, to permit of the possibility of a curve of the form A B C, the rate of the evolution of gas must be very different from anything previously known.

106. There is another strain besides the bursting strain which must be provided for, viz. the longitudinal strain in the chase of the gun arising from the friction of the products of combustion rushing along the muzzle.

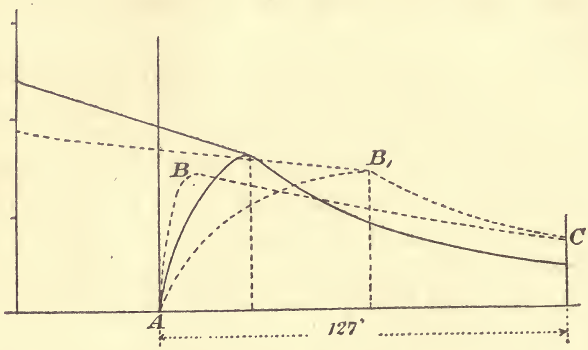
107. The importance of this strain has never been recognised by gun-makers, nor do there appear to have been any experiments made to ascertain its magnitude. In 'Internal

D

Ballistics' reasons have been given for attributing to it a very considerable magnitude, and indeed there can be little doubt on the subject.

108. To what extent the magnitude of this strain will be affected by the use of the new powder can only be conjectured. On the one hand, the volume, pressure, and temperature of products of combustion are considerably greater.

FIG. 5.



On the other hand, these products consist of nearly perfect gases, and the coefficient of friction will probably be less than in the mixture of gases and finely diffused liquid arising from the combustion of the old powders.

109. The subject of the longitudinal strain is of such importance that it is inconceivable to the author that gunmakers have taken no steps to ascertain its magnitude and relation to the other ballistic elements.

VI.

INFLUENCE OF THE NEW POWDER ON THE DESIGN OF GUNS.

110. It has been shown that no great improvement in ballistic effect can be looked for, consistent with safety, with the present guns and the new powder. It is, therefore, proper to give some attention to the subject of a design of gun suitable for the development of the new explosive.

111. Up to the present, the idea of gun-makers seems to be running in the old groove—low pressure and length of gun.

The French 15 cm. Q.F. Canet gun is called a gun of 48 calibres, but that is the length over all. The real length is as follows:—

$$\text{Chamber } 50 \text{ inches} + \text{chase } 227 \cdot 5 = 277 \cdot 5 \text{ inches.}$$

It is only slightly chambered, and the equivalent length of the chamber is 53·2 inches. The total capacity of the gun is 7674 cubic inches, and of the chamber 1500 cubic inches, so that it is a gun of 5·116 expansions, that is to say, a very long gun.

112. But long guns are very inconvenient and objectionable, especially at sea, and the question arises whether it would be practicable to take advantage of the new powder in a short gun, even though it were at the expense of decreasing the efficiency per pound of powder.

113. The gun may be shortened in two ways:—First, by an enlarged powder chamber, which, however, has the dis-

advantage of increasing the strain upon the breech apparatus; or, secondly, by increasing the maximum working pressure.

114. To what extent this may be done cannot at present be solved in a general form, inasmuch as the relations between the ballistic effect of the new powder and the ballistic elements, such as calibre of gun, travel and weight of projectile, and "characteristics" of the new powder are unknown in this country.

115. Recourse must therefore be had to the method of curves, and to such limited information as is given in the published results contained in the first part of this paper. The question will therefore be confined to a gun resembling M. Canet's 15 cm. Q.F. gun with a calibre of 5·95 inches, and travel and weight of projectile 224·5 inches and 89 lbs.

116. Suppose (what might be easily done) a wire gun to be made so as to give the same margin of safety under a pressure of 30 tons as the Canet gun under a pressure of 18·81 tons.

By the formula (2), $P = \cdot 0172\, w^2$, and making $P = 30$, we get $w = 41 \cdot 76$ lbs., and consequently $V = 198\, w^{\frac{2}{3}} = 3253$ f.s. Let the capacity of the chamber be 45·5 cubic inches per lb. of powder, which is the same gravimetric density as in the last round of the Canet gun. (See Table II.)

The capacity of the chamber is 1500 cubic inches, and the equivalent length 53 inches, and the length of charge 47 inches.

With these data the curve Fig. 6 is constructed, the area of which is 301, which multiplied by the area of the projectile 27·4, gives 8247 foot-tons.

Deducting, as before, 20 per cent for resistances, expulsion of gases, &c., there remains 6595 foot-tons, which corresponds to a velocity of 3271 feet per inch, which is very nearly the velocity found by the formula $V = 198\, w^{\frac{2}{3}}$.

117. The weight of this gun would probably be about 7¼ tons, for on the wire construction it could be made considerably lighter in proportion than the Canet gun.

Therefore the relative efficiency of the two guns would be

Description of Gun.	Total Energy.	Energies.	
		Per Ton of Gun.	Per lb. of Powder.
Canet Q.F.	4665	744·6	141
Proposed gun	6598	910·1	158

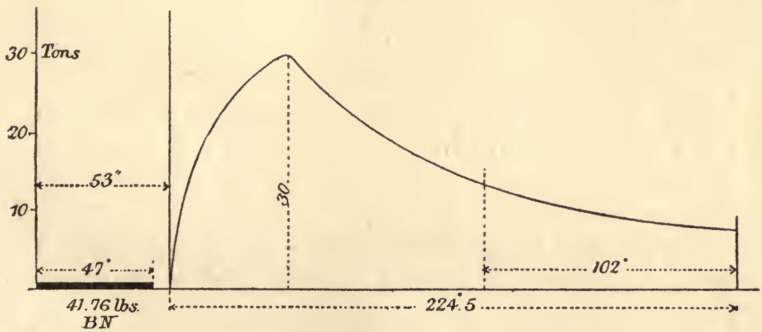
Showing the decided advantage of the high-pressure gun.

118. It may now be inquired, what would be the length of the proposed high-pressure gun which would have the same ballistic power as the Canet gun?

This may be approximately ascertained from the curve Fig. 6.

The difference of energy imparted to the projectile is 1933 foot-tons, to which must be added 20 per cent., making

Fig. 6.



2320 foot-tons, which divided by the area 27·4, gives 84·68 foot-tons to be deducted from the muzzle end of the curve, and since the mean pressure near the muzzle is about 10 tons per square inch, the length to be deducted is $\frac{84\cdot64}{\cdot10}$ = 8·46 feet or 103 inches, so that the travel of the projectile would be 122·5 inches and the total length of the gun over all, about 181 inches instead of 283 inches in the Canet gun.

119. The two guns would have the same ballistic power. The weights would be about the same, and the only difference would be the expenditure of $41\frac{3}{4}$ lbs. of powder instead of 33·08 lbs.

120. With reference to the higher pressure proposed to be used it is to be observed that the maximum pressure in a gun depends not so much on the charge of powder as on Sarrau's characteristic α, or rather on α^2, which is in his notation $= \frac{f\,a}{\tau}$, in which f is the "force" of the powder, a a coefficient depending on the form of the grain, τ the time of total combustion of the grain in free air.

121. It is, therefore, obvious that with any given powder for which f has a fixed value, the value of α^2 may be modified by a corresponding modification of a and τ, the first of which depends on the form of grain, the second on its density and least dimensions.

It is, therefore, simply an object of research to make a powder of which the characteristics α, will give the required pressure.

122. As is easily seen, the higher pressure is given by the lower value of τ, whilst at the same time it may be effected by giving such a form to the grain as will give a higher value of α.

The practical result of decreasing τ is that the evolution of gas is quickened, and the pressure rises at an earlier period of the course of the projectile, because the projectile has not had time to move out of the way.

123. It is, therefore, evident that the question of the determination of the "characteristics" of these new powders, and the size and form of grain suited to the different calibres of guns, is one of first-rate importance, and without which future ballistic progress must be a matter of hap-hazard and danger.

VII.

CONCLUSION.

124. Whilst the superiority of the new powder is incontestable, there is a danger that must be guarded against. The very fact of its being a more powerful agent renders precaution in its use the more necessary.

125. Its enormous "force" may be practically mitigated in two ways—first, by the size and density of the grain, which governs the rate of evolution of gas, and secondly, by a low gravimetric density such as has hitherto been used. By a due adaptation of these, the rate of evolution of the gas has been so proportioned to the space behind the projectile, that the pressures have been kept down to the moderate limit which the new type guns can resist; but if by any cause, such as a change of constitution of the powder under great variations of climate, or by breaking up of the grains during transport, the rate of evolution of gas is suddenly increased, then the very high "potential" of the powder may give rise to sudden abnormal increase of pressure, which the guns may be quite unable to resist, and serious accidents may occur.

126. These new powders are certainly more liable to such changes of composition than the old powders, which are simply mechanical mixtures, and therefore it is the more necessary that the guns should be strengthened to the utmost, rather than fined down to meet the requirements of anticipated low pressures.

127. The general conclusions which may be drawn from the preceding remarks are as follows :—

(1) That the smokeless powder has ballistic properties far superior to the old powders.

(2) That the erosive action on the guns will probably be less.

(3) That its use in existing guns of the new forged steel type will not lead to any considerable increase of ballistic effect *without considerable risk,* owing to the increase of pressure developed in the front part of the chase, although the actual maximum pressure on the gun may be less.

(4) That to utilise the high ballistic powers of the new powders very strong guns will be required, and that such guns will have to be much stronger *in front of the trunnions* than those of the new type forged steel guns.

That to arrive at very high ballistic results it is not necessary to have guns of inordinate length, but by the adoption of higher initial, instead of low and more uniform pressures, velocities of 3000 feet per second and upwards are attainable with perfect safety.

128. In bringing these remarks to a conclusion, the author may perhaps be allowed to give expression to opinions, which in his own mind amount to convictions, as to the future of gun construction and ballistic effects.

129. The first of these is, that low maximum pressure is a mistake. It has no *raison d'être* except the weakness of the gun. It involves a length of gun which for naval use is most objectionable. No doubt M. Canet has achieved very brilliant results with his 15 cm. Q.F. gun, but this gun is 23 feet 4 inches in length over all. A "similar" gun of 12 inch calibre would be about 46 feet 8 inches long. "Similarly" loaded it would fire a charge of B.N. powder of 264 lbs., and a projectile of 712 lbs., with a muzzle velocity of 2750 feet per second, giving a muzzle energy of 37,330 foot-tons, or 848·3 foot-tons per inch of circumference.

Now, as was shown in (§ 118), a 15 cm. gun of equal power, firing with a maximum pressure of 30 tons per square inch, would be 15 feet long, and a "similar" gun of 12 inch calibre would be 30 feet long, as against 46 feet 8 inches for the low pressure gun. There can be no doubt which gun is the most suitable for naval service.

130. A second conviction is, that guns of a very large calibre are a further mistake, and the author ventures to think that a 9-inch or 10-inch high pressure gun would be sufficient for any effect that is required against the heaviest armour afloat.

131. A third conviction is, that in order to utilise the new powders recourse must be had to the wire system of construction, by which alone guns of sufficient strength can be obtained.

132. Lastly, he would express the opinion that no time should be lost in carrying out such a series of experiments as will enable formulæ analogous to those of M. Sarrau to be constructed for these new powders, and also for the determination of the tensile strain on the chase caused by the friction of the products of combustion.

APPENDIX A.

DECOMPOSITION OF NOBEL'S POWDER AS A TYPE OF THE SMOKELESS POWDERS.

According to Nobel's specification, No. 1471/88, 100 grammes of powder contain

	Grammes.
Nitroglycerine	23·10
Nitrocellulose	23·10
Perchloride ammonia	50·35
Camphor	3·45

After explosion these give rise to new products, viz.:—

From the Nitroglycerine.

	Grammes.
Carbonic acid	13·435
Nitrogen	4·275
Oxygen	·814
Water	4·579
Total	23·10

From the Nitrocellulose.

	Grammes.
Carbonic acid	10·670
Carbonic oxide	6·791
Hydrogen	·343
Nitrogen	3·112
Water	2·183
Total	23·10

From the Camphor.

	Grammes.
Carbon	2·81
Hydrogen	0·33
Oxygen	0·33
Total	3·47

From the Perchloride of Ammonia.

	Grammes.
Chlorine	16·63
Oxygen	25·87
Nitrogen	6·47
Hydrogen	1·39
Total	50·35

Certain of the products of the camphor and perchloride unite, and the final result of the decomposition is

	Grammes.
Carbonic acid	41·26
Nitrogen	13·86
Water	25·24
Chlorine	16·64
Oxygen	2·96
Total	100·00

Volume of Gaseous Products.

The volume of the products in the last paragraph at 0° Centigrade and 0·76 metres of mercury would be

	Cub. Decimetres.
Carbonic acid	20·87
Nitrogen	11·04
Watery vapour	31·31
Chlorine	8·21
Oxygen	2·08
Total	70·51

Therefore, from 1 gramme of powder the volume of gas = ·7051 cubic decimetres, or 705·1 cubic centimetres.

In the above the water has been considered as in the state of a permanent vapour, though of course that is impossible at 0° Centigrade, but as forming part of the products of combustion it is always in the gaseous form, and may therefore properly be comprised among the gaseous products, proper allowance being of course made when the evolution of heat is considered, for the heat absorbed in the vaporisation of the water.

Heat evolved per Gramme of Powder.

Reverting to the 100 grammes of powder, the heat evolved is that evolved in the formation of 42·26 grammes of carbonic acid and 25·24 grammes of water. The first contains 11·25 grammes of carbon, and the second 2·80 grammes of hydrogen.

Consequently the heat evolved is

From Carbon ..	$11 \cdot 25 \times 8 \cdot 08 =$	$90 \cdot 9$	units Centigrade.
„ Hydrogen	$2 \cdot 80 \times 34 \cdot 46 =$	$96 \cdot 5$	„
	Total	$187 \cdot 4$	„

but the heat required to vaporise 25·4 grammes of water is

$$25 \cdot 4 \times \cdot 631 = 15 \cdot 92 \text{ units Centigrade.}$$

Deducting which there remains 171·48 units, or for 1 gramme of powder 1·7148 units Centigrade.

Temperature of Products.

This can only be given as a comparison with other powders, and not as the real temperature existing in the gun under circumstances when the loss of temperature due to cooling and the specific heat at very high pressure and temperature are both unknown.

The temperature now in question is what might be called the potential temperature or the theoretic temperature, and is calculated on the assumption that there is no loss by cooling, and that the specific heat remains constant.

Under these conditions it may be compared with the potential or theoretic temperature of ordinary powders.

NOBEL'S POWDER.—MEAN SPECIFIC HEAT OF PRODUCTS.

Carbonic acid	41·26	× ·172	=	7·097
Nitrogen	13·86	× ·173	=	2·398
Watery vapour	25·40	× ·337	=	8·506
Chlorine	16·64	× ·086	=	1·431
Oxygen	2·96	× ·155	=	0·459
	100·00			19·891

Therefore the mean specific heat = 0·199.

TEMPERATURE.

Since the heat evolved is 1·7148 units per gramme, or 1714·8 units per kilogramme, the temperature will be

$$\frac{1714 \cdot 8}{\cdot 199} = 8673^\circ \text{ C.}$$

APPENDIX B.

In order to compare with the Nobel powder, Pebble powder is taken as a type of the old powders, and its composition, as given by Noble and Abel in their 'Researches on Explosives' ('Trans. Royal Society,' 1880), is

	Parts.
Saltpetre	·7467
Sulphate (*sic*)	·0009
Sulphur	·1007
Carbon	·1212
Hydrogen	·0042
Oxygen	·0145
Ash	·0023
Water	·0095
	1·0000

And the products of combustion of 1 gramme at 0° Cent. and 0·76 metres of mercury

	Grammes.	Vols. in $cm.^3$
Carbonic acid	·2627	132·9
Carbonic oxide	·0468	37·1
Nitrogen	·1099	87·5
Sulphydric acid	·0109	9·2
Marsh gas	·0006	0·8
Hydrogen	·0006	6·7
Watery vapour	·0006	11·7
	·4410	285·9

The remaining products consist of about ·56 gramme of salts, chiefly of potassium and sulphur, which whilst in the gun are in the form of a liquid diffused throughout the gases and at the same temperature.

Heat Evolved.

The heat evolved from 1 gramme of powder is that due to the combustion of the carbon and hydrogen in it.

The carbon is as follows :—

			Grammes.
From Carbonic acid	..	$\cdot 2627 \times \frac{6}{22} =$	$\cdot 0717$
„ Carbonic oxide	..	$\cdot 0468 \times \frac{6}{14} =$	$\cdot 0201$
„ Marsh gas ..	..	$\cdot 0006 \times \frac{6}{7} =$	$\cdot 0005$
	Total		$0 \cdot 0923$

The hydrogen is—

In Sulphydric acid ..	..	$\cdot 0109 \times \frac{1}{17} =$	$\cdot 00063$
„ Marsh gas	..	$\cdot 0006 \times \frac{1}{7} =$	$\cdot 00009$
„ Water	..	$\cdot 0006 \times \frac{1}{9} =$	$\cdot 00006$
„ „	..	$\cdot 0095 \times \frac{1}{9} =$	$\cdot 00106$
	Total		$\cdot 00184$

Consequently the heat evolved is—

			Units.
From Carbon to Carbonic acid	..	$\cdot 0717 \times 8 \cdot 08 =$	$0 \cdot 5793$
„ „ „ Carbonic oxide	..	$\cdot 0201 \times 2 \cdot 473 =$	$\cdot 0497$
„ „ „ Marsh gas ..	..	$\cdot 0005 \times 8 \cdot 08 =$	$\cdot 0041$
„ Hydrogen	..	$\cdot 00184 \times 34 \cdot 46 =$	$\cdot 0634$
			$\cdot 6965$

From this must be deducted the heat required to vaporise the water, or

		$\cdot 0101 \times \cdot 631 =$	$\cdot 0063$
	Total		$\cdot 6902$

Mean Specific Heat.

This is given by Noble and Abel as $\cdot 187$.

Temperature (Potential or Theoretic).

The heat evolved from 1 kilogramme is $690 \cdot 2$ units, therefore temperature $\frac{690 \cdot 2}{\cdot 187} = 3690°$ Cent.

APPENDIX C.

Velocity and Pressure in 5·905 inch Q.F. Canet Gun with 54 lbs. P. Powder.

Ballistic Elements.

c	l	w	W	Δ	Log $\alpha\beta^{-\frac{3}{8}}$	Log α^2
5·905	224·5	54	89	1	·23014	·43223

Formula for Velocity. (' Internal Ballistics, p. 137.)

$$V = M\alpha\beta^{-\frac{3}{8}} \frac{w^{\frac{3}{8}}\Delta^{\frac{1}{4}}c^{\frac{1}{8}}l^{\frac{3}{16}}}{W^{\frac{7}{16}}}; \text{ therefore}$$

Formula for Pressure: $P = K\alpha^2\Delta\left(\frac{W w}{c^2}\right)^{\frac{1}{2}}$

$$\begin{aligned}
\log M &= 2{\cdot}84567 \\
\text{,, } \alpha\beta^{-\frac{3}{8}} &= {\cdot}23014 \\
\text{,, } w^{\frac{3}{8}} &= {\cdot}64963 \\
\text{,, } \Delta^{\frac{1}{2}} &= {\cdot}00000 \\
\text{,, } c^{\frac{1}{8}} &= {\cdot}09640 \\
\text{,, } l^{\frac{3}{16}} &= {\cdot}44055 \\
\hline
& \ 4{\cdot}26269 \\
\text{Deduct } \log W^{\frac{7}{16}} &= {\cdot}85281 \\
\hline
\log V &= 3{\cdot}40988 \\
\therefore V &= 2570 \text{ f. s.}
\end{aligned}$$

$$\begin{aligned}
\log K &= {\cdot}61174 \\
\text{,, } \alpha^2 &= {\cdot}43223 \\
\text{,, } \Delta &= {\cdot}00000 \\
\text{,, } W^{\frac{1}{2}} &= {\cdot}97470 \\
\text{,, } w^{\frac{1}{2}} &= {\cdot}86619 \\
\hline
& \ 2{\cdot}88486 \\
\text{Deduct } \log c^2 &= 1{\cdot}54249 \\
\hline
\log P &= 1{\cdot}34237 \\
\therefore P &= 22{\cdot}00
\end{aligned}$$

POSTSCRIPT.

WHILST the above pages were passing through the press I have read an interesting article, in the 'United Service Magazine' of August 1890, by Professor Lewes, of the Royal Naval College, on "The Present State of the Powder Question." Agreeing generally in the Professor's conclusions, I must take exception to one or two of his remarks. I do not agree that a perfect powder is one of which the production of gas goes on until the projectile reaches the muzzle of the gun. Such a powder would be very wasteful, and would carry the region of high pressure much too far forward in the gun.

Then, again, I think there must be some mistake in the diagram which is given as representing the pressures in the chase with the three powders P_2, Bl. Prism, and Br. Cocoa. The areas of the three curves A, B, and C, if correct, must be proportional to the muzzle energies of the projectile. The velocities are proportional to the square roots of the respective energies, that is to say, to the square root of the areas of the curves.

Now, these three curves are represented by the relative numbers 69·5, 76, and 67·5, the square roots of which are 8·33, 8·72, and 8·22, respectively.

Consequently, assuming the velocity of 1608 feet per second to be correct for the P_2 powder, the other velocities as represented by the curves would be, Black Prismatic 1683 feet, and Brown Cocoa 1586 feet per second, instead of 1708 and 1798 feet per second as given by Professor Lewes. It is therefore evident that there must be some mistake in the curves shown in the diagram.

I am very glad to see that Professor Lewes insists strongly on the importance of the question of the stability of the new powders.

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